

The Benefits of Nuclear Thermal Propulsion (NTP) in an Evolvable Mars Campaign

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Abstract

The Nuclear Thermal Rocket (NTR) represents the next evolutionary step in cryogenic liquid rocket engines. Deriving its energy from fission of Uranium (U)-235 atoms contained within fuel elements that comprise the engine's reactor core, the NTR can generate high thrust at a specific impulse of ~900 seconds or more – twice that of today's best chemical rockets. During the last three years, the Nuclear Cryogenic Propulsion Stage (NCPS) project, funded under NASA's Advanced Exploration Systems program, has been focused on recapturing fabrication techniques, maturing and testing "heritage" fuel element (FE) designs in preparation for selecting between the two primary fuel forms previously identified by DOE and NASA – NERVA "composite" and UO_2 in tungsten "cermet" fuel. The NCPS Phase 1 effort also included Mission Analysis, Engine Conceptual Design, and Requirements Definition. "Point-of-Departure" (POD) designs for both small "criticality-limited" and full-size (~25 klb_f) engines were developed by GRC and DOE's Idaho National Laboratory for both fuel types. A "common" FE design approach was utilized allowing scaling to higher thrust engines by increasing the number of elements into larger diameter cores producing greater thermal power output. Engine performance parameters for robotic science, cargo delivery and crewed exploration missions were also determined (Table 1) for three different thrust-class composite fuel engines: 7.4 klb_f (criticality-limited), 16.7 klb_f (SNRE-class) and 25 klb_f (Pewee-class). The presentation provides a brief description of each engine type and their application in a series of increasingly more difficult missions that culminate in a crewed mission to Mars – sometimes referred to as the Evolvable Mars Campaign.

Table 1. Engine Performance Parameters for Science, Cargo and Crewed Exploration Missions

| Requirements Missions | Engine Thrust (klb _f) | T/W _{eng} | T _{ex} (°K) | I _{sp} (s) | No. Engines | Fuel Loading (gU/cm ³) | U-235 Mass (kg) | Longest Single burn (min) | Total burn duration (min) | No. burns |
|------------------------------|-----------------------------------|--------------------|----------------------|---------------------|-------------|------------------------------------|-----------------|---------------------------|---------------------------|-----------|
| Robotic Science | 7.4 | ~1.9 | 2736 | 894 | 1 | 0.6 | 27.5 | ~22 | ~29.5 | 2 |
| Lunar Cargo | 16.7 | ~3.1 | 2726 | 900 | 3 | 0.6 | 60 | ~21.4 | ~49.2 | 5 |
| Lunar Piloted | 16.7 | ~3.1 | 2726 | 900 | 3 | 0.6 | 60 | ~20.9 | ~55 | 5 |
| NEA - <i>Apophis</i> Piloted | 25 | ~3.5 | 2790 - 2940 | 906-940 | 3 | 0.25 | 36.8 | ~25 - 37.2 | ~43.8 - ~77.3 | 4-5 |
| Mars Cargo | 25 | ~3.5 | 2790 - 2940 | 906-940 | 3 | 0.25 | 36.8 | ~22 | ~38 | 2 |
| Mars Piloted | 25 | ~3.5 | 2790 - 2940 | 906-940 | 3 | 0.25 | 36.8 | ~44.5 | ~79.2 | 4 |